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Immortalized epithelial tumor cell 08/981583

B') BACKGROUND OF THE INVENTION

The present invention relates to epithelial tumor cells with metastatic potential which have integrated in their genome or another replicative genetic element at least one externally introduced immortalizing oncogene and optionally at least one gene encoding an immunostimulatory factor which are expressed in such tumor cells. The invention further relates to antibodies which specifically recognize the epithelial tumor cells of the invention, to processes for the production of said tumor cells as well as pharmaceutical and diagnostic compositions comprising said tumor cells and antibodies, respectively. Finally the present invention relates to the use of the epithelial tumor cells and/or antibodies of the invention for the preparation of tumor vaccines and medicaments for the prophylaxis and/or treatment of cancer and/or the metastasis of cancer.

Malignant tumors of epithelial tissues represent the majority of all new cases of cancer and fatalities due to cancer in the industrially developed countries of the Western world such as Germany. Due to the advancement in the early diagnosis of cancer the percentage of patients with an operable primary tumor has constantly risen during recent years. As a consequence the cancer mortality rate is increasingly determined by the early primary diagnosis of cancer at the time of which tumor cell dissemination is not yet apparent (Early breast cancer trialists' collaborative group, The Lancet 339:1, 1992; Frost and Levin, The Lancet 339:1458, 1992). Since so far single, disseminated tumor cells can neither be demonstrated in tissue using high-resolution imaging diagnostic procedures nor with conventional histopathological tests, (Schlimok et al., Proc. Natl. Acad. Sci. USA 84:8672, 1987), the prognosis

factors considered for a therapy decision for the patient only depends on statistical indices of the prognosis. Systemic adjuvant therapies applied after the surgical resection of the primary tumor for the secondary prevention of metastatic relapse are often accompanied by serious toxic side-effects (Hillner and Smith, New Engl. J. Med. 324:160, 1991; Early breast cancer trialists' collaborative group, loc. cit.).

Therefore, a need in the art exists to identify epithelial tumor cells prone to become the nucleus of a metastasis at a stage of tumor development as early as possible. Additionally, it would be highly advantageous to provide an experimental system which is suitable for the identification of such tumor cells after dissemination from the primary tumor and infiltration of a secondary tissue. The identification of said tumor cells could then be used to develop detection means for said cells as well as pharmaceutical compositions which may be employed in the prophylaxis or treatment of metastasis.

So far the successful development of the desired methods and tumor cells, respectively, has been hampered by a variety of factors. One of said factors is the development of suitable antibodies which specifically recognize epithelial tumor cells with metastatic potential. Another problem is that prior to the formation of metastasis, these tumor cells can be found only in very low percentages in the infiltrated tissue such as bone marrow, said percentages being in the range of 10^{-5} to 10^{-6} . Since these cells do not divide but rest in the infiltrated tissue, conventional tumor therapies which rely on cell proliferation, fail with the eradication of these cells. Moreover, a different expression of surface markers as compared to primary tumor cells allows the epithelial tumor cells with metastatic potential in general to evade from antibody based diagnosis or therapy.

Finally, DE-PS 44 22 570 discloses a method of transforming stromal cells with a replication deficient SV40 virus. Whereas this result might have been expected, since the

SUMMARY OF THE INVENTION

transforming principle of SV40, the large T antigen, is known to interact (and inactivate or interfere with) the tumor suppressor gene p53 which in turn controls the transition of the G0 into the G1 cell cycle phase, the person skilled in the art would not expect any corresponding result in the case of tumor cells (Levine et al., Brit. J. Cancer, 69:409, 1994, Sussi et al., In. J. Cancer, 57:1, 1994). This is because the p53 protein is known to be frequently defective or absent in epithelial tumor cells (Harris and Hollstein, N. Engl. J. Med. 329:1318, 1993) and still do these cells grow even worse in culture than normal adherent cells. An interaction of the SV40 large T antigen would therefore not, according to all reasonable explanations, lead to a proliferative response of immortalized tumor cells.

In view of the above recited difficulties the technical problem underlying the present invention was to provide an epithelial tumor cell with metastatic potential that can be used for the study and development of compounds or compositions of diagnostic and therapeutic value.

The solution to said technical problem is achieved by providing the embodiments characterized in the claims.

Accordingly, the present invention relates to an epithelial tumor cell with metastatic potential which has integrated in its genome or another replicative element an externally introduced immortalizing oncogene which is expressed in said cell.

The tumor cell of the present invention may be used to generate large quantities of cells that are derived from the earliest metastasizing cells and that apparently have conserved the phenotype of the residual tumor cells present in the patient. The availability of such cells opens a new avenue to an in-depth molecular analysis of cancer

micrometastasis and may, e.g., be useful as a novel source for autologous tumor cell vaccines. The great advantage of this source is that it could be applied in the critical stage of minimal residual cancer, when the tumor load is minimal and the immune system is still intact.

The term "metastatic potential" describes the potential of said epithelial tumor cell to be the nucleus of metastatic formation. It is known that the formation of tumor cells is a complex and multistage process. The first step is the generation of cell variants in the primary tumor which subsequently detach from the tumor coenobium and proceed after invasion and penetration of the stromal tissue to the lymph or blood vessel system (Hart and Saimi, *The Lancet* 339:1453, 1992). As is known from early work in this field, cell clones already develop in the early growth phase of a tumor which display significant differences in their metastatic behaviour. The generation of new variants can be observed during the subsequent stages of tumor progression. Molecular analysis has identified changes in cell surface marker expression to be correlated with the metastatic potential of tumor cells. Examples of such markers are ICAM-1 and certain variants of CD44 (e.g. Mayer et al., *The Lancet* 342:1019, 1993). It has furthermore been found that the down regulation of the expression of desmosomal adhesion molecules such as E-cadherin and plakoglobin is involved in the detachment of tumor cells with metastatic potential from the coenobium (e.g. Birchmeier et al., in "Contrib. Oncol.", Rabes et al., eds., Karger, Basel 1992, 95). Subsequently, the expression of motility factors (e.g. scatter factor, transforming growth factors) and the secretion of proteases (cathepsin D, metalloproteinases, plasminogenic activator) favours the invasion of detached tumor cells through the basal membrane and the surrounding stroma of the primary organ (for a review see Birchmeier and Birchmeier, *Annu. Rev. Cell Biol.* 9:511, 1993). The survival of disseminated tumor cells in the secondary organ is affected by their

ability to escape immune surveillance, proliferate in response to growth factors produced by themselves or the surrounding stroma cells, and induce angiogenesis.

The above recited processes all contribute to the metastatic potential of the epithelial tumor cell of the invention and are therefore comprised by this term.

The term "immortalizing oncogene" relates to an oncogene with the potential to immortalize the epithelial tumor cell of the invention such that said tumor cell is thereafter capable of being continuously kept in cell culture. The term "immortalizing" therefore differs in the context of the present invention from the term "transforming" which denotes the capacity of a transforming principle to promote the transition of a normal cell into a dividing or non-dividing tumor cell. A transformed cell is characterized by loss or reduction of adherence dependent growth, loss of contact inhibition, and serum or growth factor independence.

Said immortalizing oncogene is expressed upon integration into a chromosome or another replicative genetic element such as stable mini-chromosomes in said epithelial tumor cell. In the case of EBV or papilloma virus, viral DNA can be found in the cell as episomes. Whereas said oncogene will usually employ the expression machinery of the immortalized cell, the regulatory sequences directing the expression of said oncogene may be both of intracellular or extracellular origin.

In a preferred embodiment of the present invention, said epithelial tumor cell is a disseminated tumor cell.

The term "disseminated tumor cell" refers to the fact that the tumor cell has already detached from the coenobium. It may e.g be in the blood stream or in the lymph system or be

In a further preferred embodiment, the tumor cell of the invention is an autologous tumor cell:

In the context of the present invention, the term "autologous" means that the tumor cell is derived from the same organism into which it is, usually after genetic or other manipulation, reintroduced, e.g. for therapeutic purposes. Alternatively, said term denotes the case that the epithelial tumor cells of the invention are kept or tested in cell culture with cells derived from the same organism.

In a further preferred embodiment, the epithelial tumor cell of the invention is a human tumor cell.

In a further preferred embodiment of the invention, said epithelial tumor cell with metastatic potential is derived from bone marrow.

The term "derived" from bone marrow" as used herein means that the tumor cell has infiltrated bone marrow and may be detected therein or isolated therefrom. Said term is not intended to mean that said tumor cell was before transformation a normal bone marrow cell.

The use of bone marrow as a preferred source of epithelial tumor cells with metastatic potential is based on the fact that the bone marrow compartment is a relatively easily accessible. Further, a number of epithelial tumors preferably invades the skeletal system (Zetter, New Engl. J. Med. 332:605, 1990). This may be explained by the finding that the last three steps of the cascade to metastasis development, namely the so-called arrest, the extravasation and the proliferation into the invaded tissue strongly

depend on tissue specific factors and are obviously favoured in the bone marrow.

A further preferred embodiment of the present invention relates to the above-characterized epithelial tumor cell wherein the immortalizing oncogene is a DNA encoding the early region of SV40 DNA and preferably the large T antigen of a replication deficient SV40 virus.

The term "DNA encoding the early region of SV40 DNA" is intended to mean any DNA molecule irrespective of the actual nucleotide sequence which encodes a large T antigen, small t antigen and/or the 17K T antigen, or a truncated form thereof, said T(t) antigen or truncated form thereof being capable of immortalizing the host cell. As a rule, the DNA encoding the large T antigen, small t antigen and/or 17K T antigen will be introduced into the tumor cell as a part of the complete or partial SV40 genome. The proper expression requires the SV40 enhancer at the 5' end and the poly A signal (AATAAA) at the 3' end (bp 2603) of the SV40 sequence.

The term "replication deficient SV40 virus" relates to the fact that the origin of replication of the SV40 DNA is not capable of being replicated or unwound. The replication deficiency can be caused by mutations in the origin of replication. Alternatively mutations in the SV40 early coding region can cause a replication defect.

In accordance with the present invention, the replication defect may most preferably be caused by (a) defect(s) such as (a) point mutation(s), (a) deletion(s), (an) insertion(s) etc. in the so-called "origin of replication" (ORI) of the SV40 genome.

In another most preferred embodiment of the invention, said replication defect is caused by one or more mutations,

In a further preferred embodiment of the present invention, at least one additional oncogene is integrated in the genome of the epithelial tumor cell.

Said additional oncogene may enhance the percentages of tumor cells which are immortalized upon the integration of the externally introduced immortalized oncogene.

In a most preferred embodiment of the present invention, said additional oncogene is ras, mutant WT1 (Wilms tumor), bcl-2, p53mut, myc, HER 2/neu, an HPV16 oncogene, an HPV18 oncogene or E1A. Depending on the host cell an additional oncogene could enhance or supplement the effect of SV40 T(t) antigens and related proteins.

A further preferred embodiment of the present invention relates to a tumor cell which has additionally integrated in its genome or another replicative genetic element at least one externally introduced gene encoding an immunostimulatory factor.

Modulation of immune response through the use of tumor cells genetically transduced with cDNA coding for cytokines (e.g. IL-2, IL4, IFN- α , IFN- γ) showed that it is possible to substantially improve tumor responses in animals; in some cases long term remissions of metastatic disease was achieved (reviewed in: Blankenstein T, Rowley DA; Schreiber H, 1991. Cytokines and Cancer: Experimental systems. Curr. Opin. Immunol. 3:694). More recently it was shown that most tumor cells lack important co-stimulatory factors such as proteins encoded by the B7 genes, which are required to induce an effective cellular immune response (reviewed in: Guinan EC, Gribben JG, Boussiotis VA, Freeman GJ, Nadler LM, Pivotal role of the B7:CD28 pathway in transplantation tolerance and tumor immunity. Blood 84:3261-3282, 1994). The transduction of these genes in tumor cells has resulted in a marked anti-tumor immune response in animal experiments. The expanding knowledge on the in vivo roles of cytokines and co-stimulatory factors should allow optimal combination therapies of cells and cytokines in the treatment of cancer in man.

In a most preferred embodiment, said immunostimulatory factor is B7 or a cytokine, e.g. IL-2, IL-4, IL-7, IFN- α or IFN- γ .

The term "specifically recognizes the epithelial tumor cell of the invention" means that the antibody is capable of distinguishing between the normal epithelial cell from which the tumor cell with metastatic potential is derived and a primary epithelial tumor cell on the one hand and the immortalized epithelial tumor cell with metastatic potential of the present invention on the other hand.

The antibody of the invention may be a polyclonal, a monoclonal, a chimeric, a synthetic or a semisynthetic antibody. The generation of such antibodies including the design of immunogens, the immunization strategy as well as the isolation of the antibodies may follow well established protocols which are described e.g. in Harlow and Lane, Antibodies, A Laboratory Manual, CSH Press, Cold Spring Harbor 1988.

The term "derivative of said antibody or said fragment thereof" refers to a modified antibody or fragment of the

In a most preferred embodiment of the present invention, said antibody is a monoclonal antibody.

The present invention relates further to an in vitro process for the production of the tumor cell of the invention comprising the step of incorporating DNA comprising DNA encoding at least one immortalizing oncogene and optionally at least one gene encoding an immunostimulatory factor into a non-immortalized epithelial tumor cell with metastatic potential.

The process of the present invention for the first time allows the specific and unlimited expansion of tumor cells of epithelial origin with metastatic potential. In principle, the present invention can be applied to all cases where a selective expansion of a defined subpopulation of rare cells is wanted. Examples for such an application are the expansion of fetal erythroblasts from the maternal blood for the purpose of genetic diagnosis of inborn defects, and the expansion of hematopoiesis-supporting bone marrow stroma cells located in the close neighborhood of hematopoietic stem cell clusters, which could be used as feeder cells to enhance expansion of stem cells in vitro (e.g. for autologous stem cell transplantation of cancer patients undergoing high dose chemotherapy). The step of incorporation may comprise any suitable incorporation method. In a preferred embodiment of the method of the invention, said incorporation comprises microinjection or bombardement of the target cells with DNA-coated

The expansion is most conveniently carried out under the following conditions: A standard culture medium (RPMI 1640) is supplemented with standard ingredients including 10 % fetal calf serum, 10 μ g/ml transferrin, 5 μ g/ml insulin, and 2 mM glutamine. According to the general rules of adherent cell culturing, the media are changed once to twice a week and fresh growth factors (as indicated below) are added to the cultures. At confluency the adherent cells (including the epithelial tumor cells) are removed by a standard

technique (incubation with trypsin/EDTA) and passaged into new culture flasks.

In a particularly preferred embodiment of the process of the present invention, said primary expansion comprises the step of culturing tissue or a body fluid comprising non-immortalized epithelial tumor cells in a suitable medium promoting the expansion of said tumor cells.

In a most preferred embodiment, said body fluid is bone marrow, blood, ascites or pleural exsudate.

In a further particularly preferred embodiment of the process of the present invention, the medium promoting the expansion of tumor cells comprises recombinant human (rh) EGF (epidermal growth factor) and/or rh bFGF (basic fibroblast growth factor).

In a further particularly preferred embodiment, the culturing step comprised in the method of the invention is carried out in extracellular matrix (ECM)-coated tissue flasks and/or at reduced oxygen concentrations of 5-10%. ECM provides important signals that inhibit apoptosis and support growth of epithelial tumor cells.

The present invention relates additionally to a pharmaceutical composition comprising the epithelial tumor cell of the invention and/or the antibody, derivative or fragment thereof of the invention, optionally in combination with a suitable pharmaceutical carrier.

The pharmaceutical composition of the present invention may be used for the prophylaxis of cancer. The pharmaceutical composition of the present invention may further be used for the treatment of cancer and/or metastasis of cancer.

The pharmaceutical composition containing the epithelial tumor cell of the invention may form the basis of an autologous or allogenic tumor cell vaccine, generated by suitable formulation and/or genetic modification of the cells such as transfection with immune stimulatory molecules and/or cytokines.

In a further preferred embodiment of the invention, the epithelial tumor cell or its genetic modification generated by transfection with immune stimulatory molecules and/or cytokines may be used to ex vivo stimulate a patient's immune cells isolated by known methods such as leukapheresis or isolation with magnetic beads. Reinfusion of such stimulated cells may generate an effective immune response to a patient's tumor.

In a further preferred embodiment the antibody, derivative or fragment thereof of the invention may be administered to a patient after surgical removal of a primary tumor in order to prevent tumor relapse.

The risk of tumor relapse for the individual patient will need to be precisely assessed and may vary depending on the presence of micrometastatic cells in bone marrow (Schlimok et al., Proc. Natl. Acad. Sci. 84:8672, 1987; Schlimok et al., Eur. J. Cancer 27:1461, 1991; Cote et al., J. Clin. Oncol. 9:1749, 1991; Diel et al., J. Clin. Oncol. 10:1534, 1992; Mansi et al., Br. J. Cancer 27:1552, 1991.; Harbeck et al., Br. J. Cancer 69:566, 1994, Lindemann et al., Lancet 340:685, 1992; Pantel et al., Cancer Res. 53:1027, 1993). A clear advantage of the minimal residual disease stage as target for a specific immunization approach is the accessibility of early disseminated cells, which frequently lodge in mesenchymal compartments, where potential effector cells abound (Riethmüller and Johnson, Curr. Op. Immunol. 4:647, 1992; Pantel and Riethmüller, Oncology Today 11:4, 1994).

Additionally, the present invention relates to a diagnostic composition comprising the epithelial tumor cell of the invention and/or the antibody of the invention.

The diagnostic composition of the present invention may be used for the detection of an epithelial tumor cell with metastatic potential in any suitable tissue such as blood and bone marrow.

Further, the present invention relates to the use of the epithelial tumor cell of the invention for the preparation of a medicament for the prophylaxis and/or treatment of cancer and/or metastasis of cancer.

The present invention also relates to the use of an antibody or derivative or fragment thereof of the invention for the preparation of a medicament for the prophylaxis and/or treatment of cancer and/or metastasis of cancer.

Finally, the present invention relates to the use of the epithelial tumor cell of the invention or the antibody or derivative or fragment thereof of the invention for the preparation of a tumor vaccine.

The figures show:

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1: Construction of transformation vector.

pUC12 is a member of a family of vectors with several common features. They contain a multiple cloning site in the lacZ-gene and carry an ampicillin resistance gene (Vieira, J. and Messing, J., Gene, 19:259, 1982; Yanish-Perron, C., et al., Gene, 33:103, 1985). pUCIn wt was cloned by introducing the 4697 basepair SV40 genome fragment BamHI (bp 2533)-origin of replication- PstI (bp 1988) containing the origin of replication, in the linker

of pUC12. A 546 bp fragment in the late region of SV40 is deleted. The plasmid pUCIn1 contains 7359bp.

Fig. 2: Principle of Microinjection of SV 40 early gene DNA

The tumor cells were plated onto petri dishes (3.5 cm in diameter, Costar, Germany) one day before injection with the microinjector model 5171 (Eppendorf, Hamburg, Germany) mounted on an inverted IM35 microscope (Carl Zeiss, Oberkochen, Germany). After injection of 200 to 300 cells per plate, the cells were re-transferred into separate T25 culture flasks and cultured, as described above. An experienced worker needs about 30 minutes to inject 200 to 300 epithelial cells. Since non-injected cells normally die off after 4-8 weeks in culture, the SV40-transduced cells are selected by their persistent growth in culture.

Fig. 3: Expression of the SV40 large T antigen in microinjected epithelial cells from the bone marrow culture of a patient with bronchial carcinoma (magnification 125x).

Fig. 4: Primary in vitro expansion and immortalization of micrometastatic cancer cells.

(A-C) Primary cultures of bone marrow from three individual patients with prostate cancer who were staged as free of overt metastasis by conventional tumor staging procedures. At the indicated time points, the cultured cells were trypsinized and immunocytochemical screening for CK-positive tumor cells was performed. (D, E) SV 40 large T DNA-induced long term growth of micrometastatic tumor cells in culture. Primary bone marrow cultures established from a patient with either non-small cell lung cancer (D) or prostatic cancer (E) were

Fig. 5: Detection of differential expression of surface markers on primary epithelial tumor cells and on immortalized epithelial tumor cells with metastatic potential.

~~B2) For further explanations see Example 9.~~

The Examples illustrate the invention.

DETAILED DESCRIPTION

Example 1

Construction of a transformation vector encoding the SV40 large T antigen and expression thereof.

In wt (Fig. 1) was cloned by integration of the SV40 genome fragments PstI/BstXI (2471bp) and BstXI/BamHI (2226bp) from pSVIn1 (Cohen et al., J. Virol 51:91, 1984) into pUC12. The fragments from pSVIn1 contain a disrupted origin generated by an insertion of one bp in the center of the 27 bp palindrome, thereby destroying the BglI site.

Example 2

Selection of patients and isolation of bone marrow aspirates.

After obtaining informed consent, bone marrow aspirates from 128 patients with primary carcinomas of the prostate, kidney, lung, breast and colorectum were investigated (Table 1). In addition, 17 patients without evidence for an epithelial malignancy were used as control group. This group

included patients with benign tumors and inflammatory diseases.

Bone marrow aspirates were obtained from both sides of the upper iliac crest through a aspiration needle. The volumes of all aspirates ranged from 2 to 10 ml (mean: 4 ml), yielding between 10^6 and 6×10^7 (mean: 2×10^7) mononuclear cells. After centrifugation through a Ficoll-Hypaque density gradient (Pharmacia, Germany; density 1.077 g/mol) at 900 g for 30 min, interface cells were cytocentrifuged on glass slides at 150 g for 5 min (8×10^4 cells per slide). Following overnight air drying, slides were either stained immediately or stored at -80°C prior to use with preservation of epithelial antigens for at least two years. From each aspirate five slides comprising 4×10^5 nucleated cells were examined (8×10^5 cells per patient), while one additional slide served as Ig isotype control.

Example 3

Immunocytochemistry

Two anti-cytokeratin (CK) mAbs (CK2 and A45-B/B3) were used for tumor cell detection in bone marrow cytospin preparations (Debus et al., EMBO J. 1:1982; Karsten et al., Eur. J. Cancer Clin. Oncol. 21:733, 1985; Schlimok et al., Proc. Natl. Acad. Sci. USA 84:8672, 1987; Pantel et al., J. Hematother. 3:165, 1994) (1) CK2 (IgG1; kindly provided by Dr. M. Osborn, Max-Planck-Institut Göttingen, and later obtained from Dr. H. Bodenmüller, Boehringer Mannheim, Tutzing, Germany) directed to the cytokeratin polypeptide No. 18 (CK18) (Debus et al., Am. J. Pathol., 1984; Debus et al., Am J. Pathol. 114:121, 1982). CK2 stains all "normal" (non malignant) cells of simple epithelia and tumors derived thereof as well as transitional cell carcinomas and a major fraction of squamous cell lung carcinomas (Pantel et al., Cancer. Res. 53:1027, 1993; Debus et al., Am. J. Pathol. 114:121, 1984; Debus et al., Embo. J. 1:1641, 1982; Hijazi

et al., J. Urol. 141:522, 1989). (2) mAb A45-B/B3 (IgG1; kindly provided by Dr. N. Karsten, Max-Delbrück Zentrum, Berlin, Germany), which detects a common epitope of a variety of cytokeratin components, including CK8, 18 and 19 (Karsten et al., Eur. J. Cancer Clin. Oncol. 21:733, 1985; Conrad et al., Biomed. Biochim. Acta 47:697, 1988). The mAbs were used at optimal concentrations, ranging from 2.5 - 4 mg/ml. Appropriate dilutions of unrelated mouse myeloma proteins served as IgG1 isotype control (MOPC21 from Sigma, Deisenhofen, Germany).

The antibody reaction was developed with the alkaline phosphatase anti-alkaline phosphatase (APAAP) technique combined with the Neufuchsin-method for visualizing antibody binding (Cordell et al., J. Histochem. Cytochem. 32:219, 1984). Briefly, after incubation with the primary antibody, a polyvalent rabbit anti-mouse Ig antiserum (Z259, Dako, Hamburg, Germany), and preformed complexes of alkaline phosphatase and monoclonal anti-alkaline phosphatase antibodies (D651, Dako, Hamburg, Germany), were used at the dilutions recommended by the manufacturer (Dakopatts, Hamburg, Germany). To allow a fast screening for mAb-positive cells on the slides, no counterstaining was performed.

Although this example employs two specific anti-cytokeratin antibodies, the person skilled in the art knows how to obtain monoclonal antibodies which serve the same purpose. The same holds true for the generation of antibodies with other specificities which would serve the same purpose as the antibodies described in the following examples.

For double staining a combined immunogold/enzymatic technique was used that has been successfully applied to the detection of histogenic and proliferation-associated markers on disseminated tumor cells (Riesenberg et al., Histochemistry 99:61, 1993). Briefly, cells were first incubated for 45 min. with mAb ER-PR8 (Gallee et al.,

Prostate 9:33, 1986) directed to prostate-specific antigen (PSA) (IgG1, Dakopatts, Hamburg, Germany). After a thorough wash with phosphate-buffered saline, gold-conjugated goat anti-mouse immunoglobulins were incubated for 45 min. Subsequently, the slides were washed and exposed to 2% glutaraldehyde diluted in phosphate-buffered saline for 5 min. The following immunoenzymatic step was similar to the single labelling method described above, except for the use of biotinylated mAb CK2, which was developed with preformed complexes of streptavidin and alkaline phosphatase. After rinsing in distilled water for at least 15 min, the freshly prepared silver enhancement mixture (Amersham, Braunschweig, Germany) was applied for about 20 min and the reaction was monitored every 5 min by placing the slides under the microscope. To abrogate the enhancement reaction, the slides were rinsed in distilled water. All slides were examined by two independent observers in a double-blinded fashion.

Example 4

Cell culture of epithelial tumor cells

Between 1 to 6 x 10⁷ MNC were plated onto extracellular matrix-coated culture flasks (Paesel & Lorei, Frankfurt, Germany) and incubated at 5-10 % oxygen (Heraeus incubator B 5061 EK/O2, München, Germany). The culture medium contained RPMI 1640 medium supplemented with 10% fetal calf serum, 10 mg/ml transferrin, 5 mg/ml insulin, 2 mM glutamine, 10 ng/ml recombinant human epidermal growth factor (Boehringer Mannheim, Mannheim, Germany) and 10 ng/ml recombinant human basic fibroblast growth factor (PBH, Hannover, Germany).

In the first step of an in vitro expansion of the epithelial cancer cells, a 3 - 5 ml inoculum of bone marrow aspirate was incubated under culture conditions that favoured the outgrowth of epithelial cell colonies in tissue culture flasks coated with extracellular matrix proteins. By trial

Under the described culture conditions, first clusters of epithelial cells appeared within 2 weeks (Fig. 1B). Significant numbers of CK+ cells ($> 10^3$) were observed in 55 cases (43.0 %) after 4 to 6 weeks of culture (Table 2). Depending on the type of the primary tumor, the absolute number of CK+ cells usually increased by 2 to 4 logs (> 13 cell divisions) during this time. The median doubling times varied from 2 to 13 days. The concentration of CK+ cells increased with time since the hematopoietic bone marrow cells waned and died off, as demonstrated by sequential staining for the common leukocyte antigen CD 45, using mAb T9/33 (Trowbridge, J. Exp. Med. 148:313, 1978). The growth rates observed in vitro do not necessarily reflect the in vivo growth patterns. In bone-seeking tumors like cancer of the prostate, lung and breast culturing of bone marrow did not lead more frequently to outgrowth of epithelial cells than in colorectal cancer (Table 2), in whom manifest metastasis of skeleton is rare (Weiss L., Grundmann E. Thorhorst J. et al., Haematogenous metastatic patterns in colonic carcinoma: an analysis of 1541 necropsies. J. Pathol 150:195-203, 1986).

It is noteworthy that the number of CK+ tumor cells detected in a particular bone marrow sample did not correlate closely to the rate of expansion achieved in the subsequent culture. Twenty out of the 55 samples which gave rise to a significant expansion ($> 10^3$ CK+ cells per culture) presented with no detectable tumor cells per 8×10^5 MNC

analysed. With regard to the total number of MNC plated per culture ($1-6 \times 10^7$), it can be assumed that most of these cultures were performed with epithelial tumor cells present under limiting dilution conditions. On the other hand, CK+ cells detected in 15 of the 50 CK+ marrow samples failed to grow in vitro, indicating a reduced plating efficiency of these cells. To enhance the outgrowth of micrometastatic cells from these patients, a larger volume of bone marrow cells might be needed. Taken together, although micrometastatic cancer cells are presumably selected in vivo for their disseminative capability, the in vitro growth potential of these cells remains heterogeneous.

Epithelial cells, as defined by CK-staining, were not detected in bone marrow cultures from 17 patients without evidence of malignant epithelial tumors (Table 2). Also, the primary aspirates of their bone marrow were negative for CK+ cells. Therefore it appears unlikely that ectopic expression of cytokeratins (Traweek et al., Am. J. Pathol 142:1111, 1993; Galmiche et al., Blood 82:66, 1993) is induced by specific culture conditions described herein. The epithelial origin of CK+ cells in culture was further supported by the expression of PSA in the case of patients with prostate cancer (Figure 1F), as well as by the absence of the CD45 leukocyte common antigen and the mesenchymal intermediate filament vimentin, a marker for bone marrow stromal cells (Galmiche et al., Blood 82:66, 1993). Further evidence that the expanded epithelial cells are tumor-derived is provided by the presence of a mutated (codon 12) Ki-ras oncogene, detected by PCR (Kahn et al., Oncogene 6:1079, 1991), in marrow of five patients with CK+ cells. In addition, the G250 antigen associated with renal cell cancer (Oosterwijk et al., Int. J. Cancer 38:489, 1986) was found in all of the six cultures analyzed from patients with renal cell cancer.

Example 5

Microinjection of epithelial tumor cells

The expansion of epithelial tumor cells unambiguously showed that the life span of these CK+ cells in culture was limited. Although the longest survivors were viable for more than 200 days (Figure 2A), proliferation of CK+ cells ceased in more than 90% of the cultures after about 40 days, when the cells began to die off rapidly (Figure 2B,C). In order to rescue the expanded cells, it was tried to immortalize them with a well-defined oncogene. Among the various potential candidates with proven transforming capacity, the SV40 large T antigen appeared to be a most suitable one because of its well-established ability to immortalize or extend the life span of normal epithelial cells from various organs (Bartek et al., Proc. Natl. Acad. Sci. USA 88:3520, 1991; Berthon et al., Int. J. Cancer, 1992; Cussenot et al., J. Urol. 146:881, 1991; Bartek et al., Int. J. Cancer 45:1105, 1990; Fauth et al., Renal Physiol. Biochem. 14:128, 1991). For the purpose of the present invention, the observation was of particular interest that the SV40 large T antigen-transduced cells retained the differentiated phenotype of the original cells (Bartek et al., Proc. Natl. Acad. Sci. USA 88:3520, 1991; Berthon et al., Int. J. Cancer 52:92, 1992; Cussenot et al., J. Urol. 146:881, 1991).

Microinjection was chosen as an efficient route of gene transfer (Bartek et al., Int. J. Cancer 45:1105, 1990; Fauth et al., Renal Physiol. Biochem. 14:128, 1991) that allowed the selective transduction of epithelial tumor cells in the established primary marrow cultures.

The tumor cells were plated onto petri dishes (3.5 cm in diameter, Costar, Germany) one day before injection with the microinjector model 5171 (Eppendorf, Hamburg, Germany) mounted on an inverted IM35 microscope (Carl Zeiss, Oberkochen, Germany). After injection of 200 to 300 cells

per plate, the cells were re-transferred into separate T25 culture flasks and cultured, as described above.

At different time points the adherent cells were detached by trypsin-EDTA treatment and immunostained using the APAAP method. Expression of histogenetic markers was assessed by staining with the anti-CK mAbs CK2 and A45-B/B3 as well as anti-PSA mAb ER-PR8, mAb G250 to a renal cell carcinoma-specific antigen (Osterwijk et al., Int. J. Cancer 38:489, 1986), CO17-1A to the 17-1A antigen (Gottlinger et al., Int. J. Cancer 38:47, 1986), and BR55-2 to the Lewis 6 blood group precursor antigen (Blaszczyk, 1987). Expression of the SV40 large T antigen was demonstrated by labelling with mAbs 220, 419, and 416 (Harlow et al., J. Virol. 39:861, 1981). As demonstrated in Table 3, microinjection of said 200 to 300 epithelial tumor cells per culture with linearised SV40 large T antigen DNA induced the continuous growth of epithelial cells in cultures from 37 of 75 cancer patients. The growth kinetics was studied in all samples and two representative experiments are shown in Figure 3. An exponential increase in T antigen-positive cells was followed by a rapid increase in the number of CK+ cells. The transduced cells grow to confluency within 3 to 5 weeks after microinjection (Figure 1D). T antigen expression was observed after more than 150 days in culture, suggesting the stable integration of the injected DNA (Fig. 1E and Fig. 3).

Example 6

Transplantation of microinjected epithelial tumor cells into SCID mice

Subcutaneous transplantation of one of the immortalized micrometastatic lung cancer cell lines into immunodeficient SCID mice resulted in the development of local tumor growth and micrometastatic bone marrow infiltration at a frequency of 10^{-4} . Such minimal marrow infiltration was also observed with another line of immortalized prostate cancer cells when

a subcutaneous tumor was not detectable (data not shown). This finding suggests that micrometastatic cells propagated from bone marrow aspirates still inherit a particular organspecific homing affinity in SCID-mice. The reconstruction of these mice with autologous immune effector cells might therefore allow an in depth investigation of the in vivo immune response against minimal residual cancer. The development of such an animal model is of utmost importance for the preclinical testing of genetically engineered tumor cell vaccines directed against minimal residual cancer.

Example 7

Phenotypic analysis of epithelial differentiation antigens in the immortalized tumor cells

A detailed phenotypic analysis of epithelial differentiation antigens in the expanded CK+ cells is summarized in Table 3. According to the origin of the individual tumor differentiation markers such as prostate-specific antigen (Fig. 1F), intestinal-specific annexin, prolactin-inducible protein and G250 were found in SV40 T antigen immortalized CK+ cells. The experimental details are as follows:

Expression of histogenetic markers at the mRNA level was determined by reverse transcriptase PCR (RT-PCR) analysis. Total RNA of about 10^6 cells of each evaluated culture was purified with the guanidine thiocyanate method. 2 ml total RNA was reverse transcribed into cDNA using specific primers for intestine-specific annexin (ACTATGCGAATCAACGTC), prostate-specific antigen (TGACGTGATACCTTGAAGCA) and gross-cystic disease-fluid-protein-15/prolactin-inducible-protein (GTGTGGCAAACAGACAGG) (Schulz et al., Nucleic. Acids. Res. 16:6226, 1988; Wice and Gordon, J. Cell Biol. 116:405, 1992; Murphy et al., J. Biol. Chem. 262:15236, 1987). The following PCR primers were used for amplification of marker-specific cDNA:

PSA: 5'CTTGTAGCCTCTCGTGGCAG, 3'GACCTTCATAGCATCCGTGAG;
 ISA: 5'CATTGAGTTCCTGTGCACGA, 3'GACTTGTACAGACGTTTCAGC;
 PIP: 5'CAAAGCTCAGGACAACACTCG, 3'CAGCATCATCAGGGCAGATG.

The specificity of the amplification products was demonstrated by restriction enzyme analysis.

The results and above observations suggest that integration of the SV40 DNA and expression of large T antigen did not substantially change the expression pattern of the studied differentiation markers.

Recent analyses of a number of T antigen mutants have clearly shown that the specific DNA binding properties of T antigen are not essential for immortalization (Fanning and Knippers, Annu. Rev. Biochem. 61:55, 1992; Dobbelstein et al., Oncogene 7:837, 1992). However, SV40 large T antigen interacts specifically with the products of two known tumor suppressor genes, the p300 or related functions (Yaciuk et al., Mol. Cell. Biol. 11:2116, 1991) and with retinoblastoma susceptibility (RB) gene and the p53 gene, thereby neutralizing the growth-arresting properties of both proteins (Fanning and Knippers, Annu. Rev. Biochem. 61:55, 1992; Dobbelstein et al., Oncogene 7:837, 1992). In the present study, the level of p53 protein detectable by immunocytochemistry increased in immortalized micrometastatic cells, suggesting that p53 protein interacted with T antigen in these cells, which in turn prolonged the half-life of p53. Since the p53 protein is thought to be frequently defective or absent in metastatic epithelial tumor cells, it is surprising that this interaction is required to obtain the described immortalisation of micrometastatic carcinoma cells. However, extensive comparative evaluations of immortalized and parental tumor cells and studies with T antigen mutants need to be performed to determine the molecular basis for the observed immortalization. The usefulness of SV40 T antigen-transduced cells as vaccines is supported by the observation that the expression of molecules relevant to an efficient

immune response, such as MHC class I antigens and ICAM-1, is not downregulated in the genome of micrometastatic cells expressing T antigen (data not shown), which is consistent with the results of previous investigations on various other types of human and rodent cells (Galy et al., Thymus 22:13, 1993; Vidal et al., J. Immunol. Methods 166:63, 1993; Tanaka et al., Eur. J. Immunol. 23:2614, 1993). The method established here appears to be a feasible way to generate large quantities of cells that are derived from the earliest metastasizing cells and that apparently have conserved the phenotype of the residual tumor cells present in the patient. The availability of such cells opens a new avenue to an in-depth molecular analysis of cancer micrometastasis and may, e.g., be useful as a novel source for autologous tumor cell vaccines. The great advantage of this source is that it could be applied in the critical stage of minimal residual cancer, when the tumor load is minimal and the immune system is still intact (Riethmüller, G. and Johnson J.P., Current Opinion in Immunology 4 (1992), 647-655).

Example 8

In vitro generation of an autologous T cell response to micrometastatic carcinoma cells propagated from bone marrow.

For specific immunization against minimal residual cancer, micrometastatic cancer cells themselves are the ideal target candidates. The evaluation of the immune response against these tumor cells is, however, hampered by their extremely low frequency (e.g. 10^{-5} - 10^{-6} in bone marrow). In the present study, culture conditions allowing a more than 10,000-fold transient expansion of early disseminated epithelial tumor cells present in bone marrow were established. Expanded cells were immortalized by selective microinjection with SV 40 large tumor antigen DNA without gross changes in the expression pattern of epithelial antigens. In one of the cell lines (PC-MM-1) established

from bone marrow of a prostate cancer patient without distant overt metastasis (stage M₀), the gene encoding for the co-stimulatory molecule B7 was transduced in a retroviral vector. Immunostaining of these cells revealed the following phenotype: HLA-A2⁺/A3⁺, HLA-Bw4⁻/Bw6⁺ and ICAM1⁺. Incubation with 10U/ml IFN- γ for 72 h increased the expression of these molecules except for Bw4. Autologous PBL were in vitro stimulated on an irradiated monolayer of the B7 transfected tumor cells in medium supplemented with 10 U/ml IL-2 and 40 U/ml IL-4. The tumor cell monolayer was completely killed by the PBLs after three days in culture. Restimulation was performed by renewing the irradiated target monolayer once a week. After four rounds of stimulation the PBL population consisted of 75% - 85% CD3⁺CD8⁺T-cells. In a ⁵¹Cr-release assay with an effector to target ratio of 50:1 we observed a lysis of 15% to 20% B7-transfected PC-MM-1. The observation that IFN- γ pre-treated LNCap prostate cancer cells were also lysed at a similar rate suggests that the observed T-cell response might be prostate associated. In conclusion, transduction of the B7 gene into micrometastatic tumor cells might be an efficient way to enhance the cellular immune response against these cells and to generate large quantities of specific cytotoxic effector cells from peripheral blood samples.

Example 9

Detection of differential expression of surface markers on primary epithelial tumor cells and on immortalized epithelial tumor cells with metastatic potential

All experimental procedures used in this example are standard procedures. mRNA was prepared from tumor cells (RCC) and from CK⁺ cells from bone marrow and reverse transcribed into cDNA using oligo-dT-priming. "Hot" PCR, i.e. PCR with radioactively labeled material was carried out with random and oligo-dT-primers. The products of said PCR

B
B

were analysed using urea-polyacrylamide electrophoresis. Fig. 5 shows the results of two such experiments. In Fig. 5a tumor specific bands and in Fig. 5b bands specific for CK+ cells are clearly visible. Next, the bands that were differentially amplified were isolated, cloned and sequenced. Full length cDNA was obtained using conventional DNA libraries obtained from the above cells. Full-length cDNAs were cloned in E.coli, followed by recombinant protein expression in E.coli. The recombinant proteins were used to generate specific polyclonal antisera in rabbits. Specificity of the sera tumor cells with micrometastatic potential was confirmed using native tumor probes. Finally, monoclonal antibodies were generated against the specific proteins.

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TABLES

Table 1. Frequency of CK-positive micrometastatic tumour cells in bone marrow. For detection of tumour cells, mononuclear cells (MNC) isolated from bone marrow aspirates were immunostained, using the APAAP-staining technique with anti-cytokeratin mAbs CK2 and A45-B/B3.

Tumour type	Number of patients analysed	Frequency of CK-positive cells in bone marrow* (number of patients with n CK ⁺ cells per 8×10^5 MNC)		
		<1	1 - 5	6 - 10
Prostate cancer	22	8	11	1
Renal cell cancer	12	9	3	0
Lung cancer	14	9	4	1
Breast cancer	41	28	8	2
Colorectal cancer	39	24	11	1
Total :	128	78	37	5

* based on the analysis of 8×10^5 MNC isolated through density gradient centrifugation from bone marrow aspirates of the upper iliac crest and/or sternum.

Table 2. Expansion and enrichment of CK-positive micrometastatic tumour cells. Between 1 to 6×10^7 MNC obtained from bone marrow aspirates were cultured over 4 to 8 weeks.

Tumour type	Number of patients	Number of cultures with $>10^3$ CK+ cells	Maximum Expansion (x n CK+ cells) [#]	Maximum Enrichment (x conc. CK+ cells) [#]
Cancer, total	128	55 (43.0%)	11000	1.1×10^6
Prostate cancer	22	12 (54.5%)	11000	1×10^5
Renal cell cancer	12	6 (50.0%)	690	8.8×10^3
Lung cancer	14	8 (57.1%)	2830	1.1×10^6
Breast cancer	41	13 (31.7%)	4410	1.6×10^5
Colorectal cancer	39	16 (41.0%)	2440	2.6×10^4
Control group*	17	0	0	0

[#] as defined by sequential immunostaining with anti-CK mAbs CK2 and A45-B/B3 was performed before and after primary culture.

* patients with benign tumours and inflammatory diseases

Table 3. SV40 large T antigen-induced long term propagation of micrometastatic tumour cells.

Tumour type	Number of patients	Number of passages (mean value)	Epithelial markers (Number of positive cultures)
Prostate cancer	22	2 - 104 (15)	Cytokeratin (22) Prostate-specific antigen (8)
Renal cell cancer	7	2 - 6 (4)	Cytokeratin (7) G250 (4)
Breast cancer	3	4 - 16 (10)	Cytokeratin (3) Prolactin-inducible protein (2)
Lung Cancer	3	3 - 85 (36)	Cytokeratin (3) 17-1A/55-2 antigens (2)
Colorectal cancer	2	9, 12	Cytokeratin (2) 17-1A/55-2 antigens (1) Intestinal-specific annexin (1)

200 - 300 tumour cells of each patient were microinjected after primary in vitro expansion, as described hereinabove. Protein expression was assessed by immunocytochemistry with anti-CK mAbs CK2 and A45-B/B3, ER-PR8 to PSA, G250 to a renal cell carcinoma-specific antigen and 17-1A/SDZ ABL 364 to the 17-1A/BR55-2 antigens, mRNA expression of PSA, prolactin-inducible protein, and intestinal-specific annexin was determined by RT-PCR analysis.